OBJECT IDENTIFICATION AND CHARACTERIZATION WITH HYPERSPECTRAL IMAGERY TO IDENTIFY STRUCTURE AND FUNCTION OF NATURA 2000 HABITATS

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ABSTRACT:

Habitat monitoring of designated areas under the EU Habitats Directive requires every 6 years information on area, range, structure and function for the protected (Annex I) habitat types. First results from studies on heathland areas in Belgium and the Netherlands show that hyperspectral imagery can be an important source of information to assist the evaluation of the habitat conservation status. Hyperspectral imagery can provide continuous maps of habitat quality indicators (e.g., life forms or structure types, management activities, grass, shrub and tree encroachment) at the pixel level. At the same time, terrain managers, nature conservation agencies and national authorities responsible for the reporting to the EU are not directly interested in pixels, but rather in information at the level of vegetation patches, groups of patches or the protected site as a whole. Such local level information is needed for management purposes, e.g., exact location of patches of habitat types and the sizes and quality of these patches within a protected site. Site complexity determines not only the classification success of remote sensing imagery, but influences also the results of aggregation of information from the pixel to the site level. For all these reasons, it is important to identify and characterize the vegetation patches. This paper focuses on the use of segmentation techniques to identify relevant vegetation patches in combination with spectral mixture analysis of hyperspectral imagery from the Airborne Hyperspectral Scanner (AHS). Comparison with traditional vegetation maps shows that the habitat or vegetation patches can be identified by segmentation of hyperspectral imagery. This paper shows that spectral mixture analysis in combination with segmentation techniques on hyperspectral imagery can provide useful information on processes such as grass encroachment that determine the conservation status of Natura 2000 heathland areas to a large extent. A limitation is that both advanced remote sensing approaches and traditional field based vegetation surveys seem to cause over and underestimations of grass encroachment for specific categories, but the first provides a better basis for monitoring if specific species are not directly considered.

1. INTRODUCTION

Timely and accurate habitat reporting is vital for monitoring the biodiversity and ecological quality of our environment. Within Europe, The Pan-European Biological and Landscape Diversity Strategy (PEBLDS, Council of Europe, 1996), initiated the creation of an ecological network of protected areas in the EU covering valuable natural habitats and species of particular importance for the conservation of biological diversity, also known as Natura 2000 sites. These sites find their legislation in Council Directive 79/409/EEC on the Conservation of Wild Birds (the EC Birds Directive), in 1979, and Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora (the EC Habitats Directive). As a consequence, EU member states have to embody the targets in their own legislation and develop instruments and procedures to achieve the goals. Thus, the implementation of the Habitats Directive by the designation and appropriate management of 'Special Areas for Conservation' (SACs) and the accurate reporting on the conservation status, which is now obliged every 6 years, is currently the main concern for European agencies and for most of the national and regional authorities, responsible for nature conservation. The assessment of conservation status is based on four parameters (European Commission, 2005; ETC/BD, 2006a): i) area, being the sum of the patches that are actually occupied by the habitat; ii) range, being the region in which the habitat is likely to occur provided local conditions are suitable; iii) specific structures and functions, encompassing indicators of habitat quality; and iv) future prospects for the survival of the habitat in the member state's territory. For all these parameters, the conservation status needs to be determined as 'favourable', 'unfavourable-inadequate' or 'unfavourable-bad'. Criteria and thresholds for identifying the state of a certain parameter are provided by the European Commission (2005). From the experience of the first assessment on the conservation status of habitat types by the EU member states it can be concluded that the 'best available data' have many shortcomings resulting in gaps and inconsistencies in the information provided to the EC (ETC/BD, 2008). The inconsistency in information is caused by the differences between the EU member states in the interpretation of the "Explanatory Notes and Guidelines for reporting, assessment and monitoring" (European Commission, 2005) and in the applied methods for data collection and data analysis. The question is how the information gaps can be filled and how the inconsistencies in information can be solved for the next reporting periods. As the financial sources are limited, there is a need for a cost effective (and consistent) approach, making use of the best available monitoring methods suited for this purpose. Field observations are an important source of information for the assessment of the conservation status of habitat types, but are both time consuming and costly.

Remote sensing observations have an added value and are complementary to field observations as they deliver a synoptic view and offer the opportunity to provide consistent information in time and space. Remote sensing methods and especially hyperspectral techniques could be utilized to this end, but existing data and classification methods fall short for the purposes of habitat reporting in several aspects: i) airborne hyperspectral data are suitable but coverage is still limited; ii) existing methods have not addressed the issue of habitat structure and functioning which is most important for assessing habitat quality; and iii) most existing remote sensing methodologies have not been tested vigorously for operational purposes. Opportunities for space-based remote sensing in habitat and biodiversity monitoring at the regional level have recently been described in two review papers by Duro et al. (2007) and Gillespie et al. (2008). However, monitoring of habitat quality at the local level (e.g., structure and function) is still a challenging application because this requires methods which can deal with complex transitional zones present in natural vegetation. As stated by Burnett and Blaschke (2003), natural complexity can be best explored using spatial analysis tools based on concepts of landscapes as process continuums that can be particularly decomposed into objects or patches. How we can define consistently our vegetation and/or habitat patches will be part of the discussion of this paper. Geospatial object based image analysis (GEOBIA), or in other words object-based image segmentation and classification concepts and tools (Burnett and Blaschke, 2003; Blaschke 2010), are in our opinion strong tools to identify the required patches in a consistent way. At the same time, instead of looking at vegetation as a group of classified patches with sharp boundaries, one could also treat compositional variation as a continuous field. Schmidtlein et al. (2007) combined ordination measures derived from floristic field data with spectral data from HyMap to derive continuous maps which represent abrupt transitions between habitats as well as within habitat heterogeneity and gradual transitions. Another approach for continuous field mapping is the use of spectral mixture analysis (SMA). This means, that the reflectance of a single pixel is considered to be a mixture of end members, each with a specific spectrum, for a vegetation or species class presented in the pixel. Because the same endmember can be used to analyze a time sequence, SMA has the capability to estimate changes in abundance (Rosso et al., 2005). The potential to estimate the spatial distribution and abundance of species or species groups has great value in monitoring aspects related to habitat structure and function (e.g., grass encroachment), because changes can be detected and quantified.

This study assesses the integrated use of spectral mixture analysis and segmentation techniques based on hyperspectral imagery to evaluate the structure and function of a heathland ecosystem, with emphasis on grass encroachment. The proposed approach was applied on hyperspectral AHS-160 imagery, to investigate their appropriateness to characterize the spatial coverage and configuration of relevant heathland habitat types. SMA in combination with segmentation techniques is examined as a possible technique that takes advantage of the high-dimensional spectral information content of imaging spectroscopy data to discriminate continuous processes, such as grass encroachment in vegetation patches in complex ecosystems. In the discussion we will specifically focus on the opportunities for remote sensing to complement the traditional vegetation field surveys.

2. MATERIALS & METHODS

2.1 Study area

The Ginkelse and Ederheide is a heathland area in the southwestern part of the largest terrestrial Natura 2000 site in the Netherlands, called ‘Veluwe’ (91.200 ha). The site has central location in the Netherlands, but in the southern part of Veluwe. The study area Ginkelse and Ederheide is approximately 1000 ha in size and is known for its large area covered by Calluna heath vegetation. The Ginkelse Heide is the area located south of the main road N224 going from Ede to Arnhem. The Eder Heide is located north of this road. In addition to its ecological values, it has also archaeological values, such as urn fields dating back from 1100 - 500 BC. The heathland vegetation developed during the Middle Ages as result of agricultural use. For many centuries, the organic layer was removed from the surface by sod-cutting. This organic layer was transported to a stable, where it was mixed with the animal manure and re-used as fertilizer on arable land. Due to overexploitation and mismanagement, the sandy soils lost fertility and heathland and inland dune systems developed. This practice continued until the 19th century in combination with intensive sheep grazing. From the beginning of the 20th century, the Ginkelse & Ederheide became a military terrain and was intensively used for exercises. A historic milestone for the area was its use as a landing place for the paratroopers that liberated the Netherlands during the operation Market Garden in the Second World War. Heavy fighting took place in and around this area. During the last 30 years, military use has been combined with tourism (e.g., hiking, cycling). As a result ecological processes are under pressure and the landscape is continuously changing. Currently, the area is managed and owned by the Ministry of Defence. The current management objectives for the area are:

- to keep heath land vegetation (Calluna and Erica) in its optimal condition (age differentiation);
- to prevent grass encroachment;
- to prevent natural generation of trees;
- to prevent the loss of dynamic sand dunes;
- to provide optimal environmental conditions for heath fauna.

Photo 1. Sheep flock grazing on the Ginkelse heide. The problem of grass encroachment is clearly visible on the foreground (*Molinia caerulea*).

The quality of the heath land declined rapidly during the 1980s due to increased nitrogen deposition resulting in grass and shrub encroachment. Several management practices were applied to counteract this process: sod-cutting, ploughing, grazing etc. Analysis of a time-series of aerial photographs, in order to reconstruct the management over the period 1982-2006 revealed that in the 1980s ploughing was applied on a large scale. Traces of this can still be detected in the patch like structure of the heathland, especially in the Ginkelse heide. At the beginning of the 1990s, less intensive practices, such as mowing and sod cutting, came into use more frequently, however clearly at smaller spatial scales.

The heathland vegetation in this study area (Table 1) consists mainly of dry heathland dominated by *Calluna vulgaris* (Hdc). Due to succession within this habitat type different Calluna age classes can be distinguished: a) pioneer (Hdcy); b) climax (Hdca); and c) degenerating (Hdco). A heath land structure with a mixed composition of age classes (Hdcm) is considered as highly valuable. According to habitat assessment requirements for function and structure (Bijlsma et al., 2008), grass encroachment with Molinia (Hgmd) is considered a negative process while a scattered distribution (< 10%) of shrubs and trees (Fc and Fd) is considered as favourable. Finally, bare sand areas (Sb) and sand fixated dunes (Sfg) are important indicators of the occurrence of wind erosion which is considered an important process for the development of this landscape.

Heathland dry : Calluna-dominated		Hdc
	of predominantly young age	Hdcy
	of predominantly adult age	Hdca
	of predominantly old age	Hdco
	of mixed age classes	Hdcm
Heatland: Molinia dominated		Hgmd
Grassland permanent with semi-natural vegetation		Gpnd
Forest		F
	coniferous (scots pine)	Fcps
	deciduous	Fd
Sand		S
	bare	Sb
	fixated by grasses and mosses	Sfgm

Table 1: Heathland habitat types present in the study area as defined in the HABISTAT project

2.2 Hyperspectral imagery

Two flightlines with the AHS-160 (Airborne Hyperspectral Scanner) sensor were acquired over the Eder and Ginkelse heide around 11:15 a.m. on the 7th of October 2007. The aircraft, a CASA 212-200, was flown by INTA (Spain) at a height of approximately 1 km. For this study, 63 bands of the AHS-160 sensor were used, divided over the visible and near-infrared (20 bands from 430-1030 nm with 30 nm resolution), short-wave infrared region 1 (1 band from 1550-1750 nm with 200 nm resolution) and short-wave infrared region 2 (42 bands from 1995-2540 nm with 13 nm resolution). The spatial resolution was 2.4 m. Processing of the images from DN values to radiance and surface reflectance was carried out by the processing and archiving facility of VITO (Biesemans et al., 2006). The PARGE and ATCOR model were used for geometrical and atmospheric correction of the data, respectively. The spatial resolution of the final images was 2.4 m. A flightline mosaic was created for the study area, but the two flightlines remained clearly visible (Fig. 1), due to illumination differences along the edge of the flight lines.

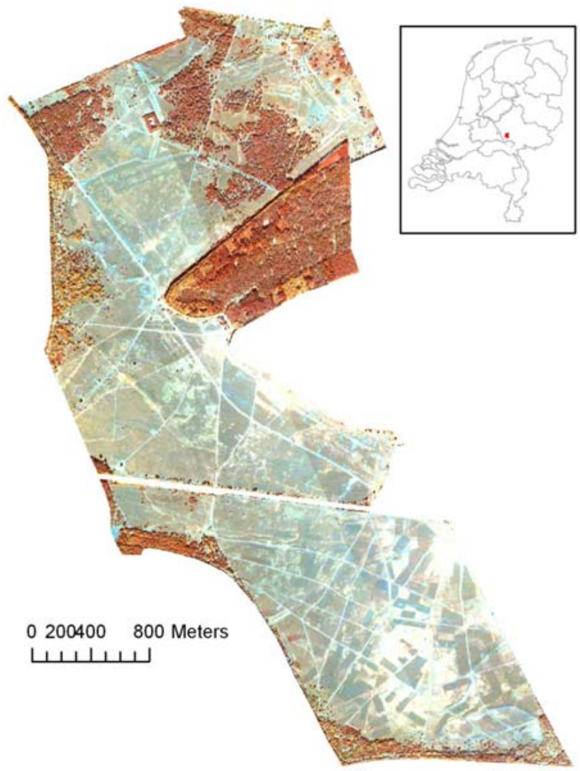

Figure 1 Location of the study area in the Netherlands. The hyperspectral image of the Ginkelse and Ederheide consists two flightlines with the AHS-160 sensor acquired on the 7th of October 2007 around 11.15 a.m.

2.3 Ground reference data

Ground reference data to train and validate the SMA were collected in the period after the image acquisition between October 2007 and April 2008. Sampling locations were selected by laying out a regular grid over the study area with a sampling distance of 250 m. Geographic coordinates for every location were collected with a Garmin handheld global position system unit. For every location a description of the habitat types was made according to the methodology established in the BioHab project (Bunce et al., 2008). For each point location with a radius of 3m, the composition of plant lifeforms was recorded by their coverage in percentage (vertical projection) together with the dominant species of every lifeform. Based on this information, a classification into habitat type was made according to the typology described in Table 1. A total of 104 plots were recorded in the study area and for every plot overhead and oblique field photos were taken. A geodatabase was available with vegetation and structure maps for different years obtained from Dienst Vastgoed Defensie (DVD). The vegetation maps contained the relevant phytosociological plant communities, and was available for 1997 with an update in 2009. The structure maps indicate the degree of grass encroachment, and was available for 2003 with an update in 2009. The maps were largely based on field surveys, supported by aerial photo interpretations. No information was available on the accuracies of these maps.

2.4 Segmentation

Since, terrain managers, nature conservation agencies and national authorities responsible for the reporting to the EU are not directly interested in pixels, but much more in information at the level of vegetation patches, groups of patches or site level, a multi-resolution segmentation was performed on the AHS-160 hyperspectral data for the spatial identification of the vegetation and/or habitat patches. Segmentation (object recognition, based on spatial characteristics) is the process of identifying spatial units, which are mostly derived from satellite imagery (Lucas et al., 2007). As stated by Burnett and Blaschke (2003), natural complexity can be best explored using spatial analysis tools based on concepts of landscapes as process continuums that can be particularly decomposed into objects or patches. The segmentation was implemented with the software eCognition (eCognition Developer 8.0) which is an object-oriented image segmentation and classification software for multi-scale analysis of Earth Observation data of all kinds (Definiens Imaging, 2005). As input for the segmentation process, the AHS mosaic was rescaled from a float to a 16-bit integer and a selection of 6 optimal bands was made in relation to vegetation characteristics, namely: b2 (blue: 0.4414-0.5220 µm), b5 (green: 05276-0.6076 µm), b8 (red: 0.6122-06740 µm), b12 (NIR: 0.7262-0.8078 µm), b21 (SWIR: 1.4699-1.7017 µm) and b30 (MIR: 2.0237-2.0705 µm). Once the objects are obtained it provides all kind of possibilities for the characterization of the objects, not in the least by combining it with the information from the SMA analysis.

2.5 Spectral Mixture Analysis

An efficient method resulting in continuous data is Spectral Mixture Analysis (SMA), also called 'spectral unmixing' (Smith et al., 1985). SMA is a method to estimate the mixing components (endmembers) of a mixed spectral signal. The linear unmixing model makes assumptions that each pixel consists of a limited number of endmembers. The endmembers were selected manually by extracting spectra from the AHS-160 image based on vegetation distribution information derived from the field observations. Candidate pixels were selected from locations were the habitat types appeared to be pure and had a relative homogeneous species composition. For all habitat types presented in Table 1, endmembers were selected as input for Spectral Mixture Analysis (SMA). A minimum noise fraction (MNF) transformation was performed on the mosaiced AHS-160 image. MNF bands occurring after an 80% variance threshold were discarded from further analysis (band 15-63). In addition, bands that contained dramatic brightness differences between flightlines in the mosaic were also removed (band 4 and 6). SMA was performed on the preprocessed MNF mosaic with 7 endmember spectra as input. The heathland age classes were grouped as one endmember. SMA was implemented using ENVI and a high weight (10,000) was assigned to the unit sum constrained factor. To assess the accuracy of SMA two methods were used. First, the fit of the SMA model was assessed based on the spatial continuous map for the root mean square error (RMSE). Higher values of RMSE indicate regions that could contain lacking endmembers. Secondly, the dataset with field observed species and habitat abundances was compared to SMA modelled abundances for these locations.

3. RESULTS AND DISCUSSION

3.1 Classification and segmentation results

At first, all six selected AHS bands were used in the segmentation process, but better results were obtained when the blue and green band were omitted. Best results were obtained with a scale parameter of 300 for the detailed vegetation patches (without using a shape and compactness factor). For more general habitat patches a coarser scale could be used (e.g. scale parameter of 1000). After the segmentation of the detailed vegetation patches, the maximum spectral difference algorithm was applied with a setting of 1500 (data range from 0 – 65535). The final result was exported to a shape file. As a reference for the segmentation a vegetation map of 1997 was used (source: Dienst Vastgoed Defensie, DVD).

The best SMA results were obtained using 7 endmembers that were carefully selected on the western side of the AHS hyperspectral image. The 7 endmembers were: Hdca, Hgmd, Gpnd, Sb, Sfgm, Fd, Fcps (Table 1). Modelled errors were especially large along the edges on the western side of the image and in the woody areas, as well as pixels located alongside roads. The addition of a shadow endmember in the SMA did not significantly improve these modelled errors. North of the N224 road, at the Eastern edge of the Western flightline, some patches clearly have lower modelled heath fractions than the surrounding areas. When these are compared to field data, they correspond well with locations that are marked as very grass encroached. They can be found as relatively high modelled fractions in the Hgmd (Figure 2) and Gpnd images.

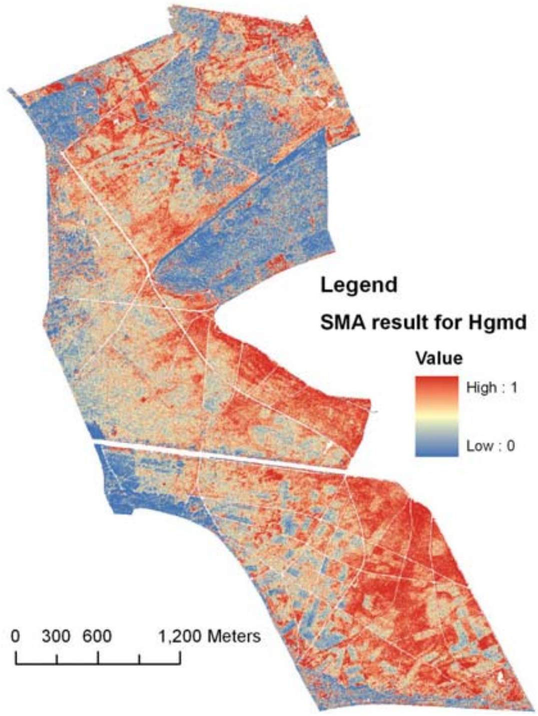

Figure 2. The result for endmember 'Hgmd' (Molinia dominated heathland) obtained by spectral mixture analysis (SMA) on a AHS hyperspectral image of October 2007.

In ARCGIS 9.3 the tool zonal statistics was used to calculate the percentage of each AHS end member within a zone (the object). Both the vegetation and segmentation map were used to provide the objects. The zonal statistics were subsequently joined (spatial join) with the original shape files of the objects. Figure 3 shows the structural information on grass encroachment for the vegetation map of 2009. Figure 4 shows the amount of grass encroachment obtained by spectral mixture analysis and segmentation of a AHS hyperspectral image. Comparison of both maps shows comparable patterns but also reveals some clear differences. In general, Figure 4 shows more detailed objects and has more equal classes of grass encroachment.

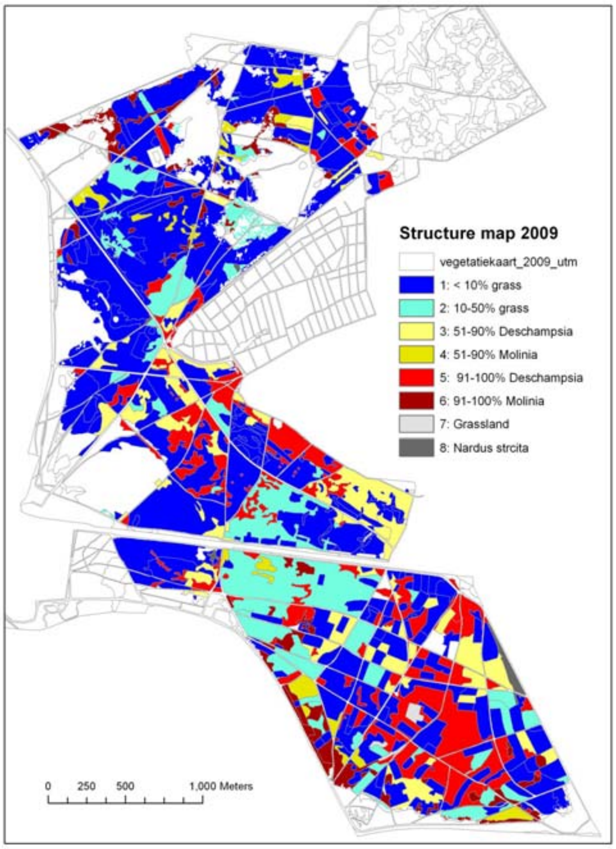

Figure 3. Vegetation structure map of 2009 indicating the amount of grass encroachment (for selected objects). Source: Dienst Vastgoed Defensie (DVD).

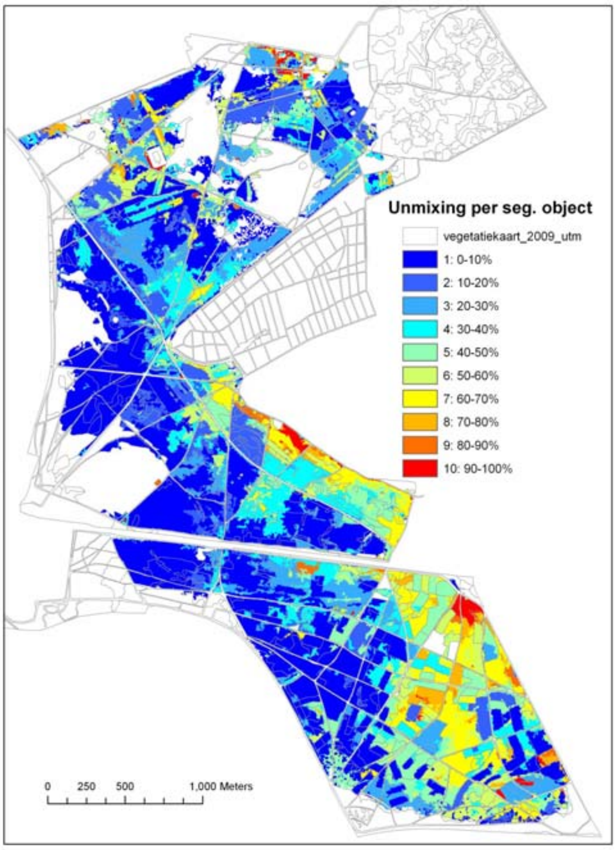

Figure 4. The amount of grass encroachment obtained by spectral mixture analysis and segmentation of AHS hyperspectral imagery.

3.2. Assessment of grass encroachment

Assessment of the results for grass encroachment was first done by a comparison of the overall statistical figures of a) the structural information from the vegetation map of 2009, b) the spectral unmixing results analysed per vegetation 2009 object, c) the spectral unmixing results per segmentation object (all obtained from the AHS hyperspectral image of 2007) and d) from 104 field samples with a 3 m radius obtained by systematic field sampling in 2008. The field samples were adjusted for the total area by a multiplication factor of 854, to obtain regional statistics (Grnd_cor). The divisional classes of grass encroachment were: I) < 10%; II) 10-50 %; III) 51-90% and IV) 91-100%.

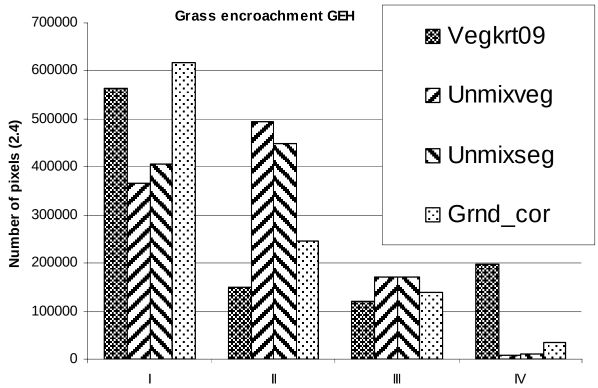

Figure 5. Statistical figures on grass encroachment for the Ginkelse and Ederheide obtained from a) the vegetation structure map of 2009 – Vegkrt09 (Source: Dienst Vastgoed Defensie); b) SMA zonal statistics for the vegetation map objects – Unmixveg; c) SMA zonal statistics for the segmental objects – Unmixseg; d) systematic field samples corrected for total area – Grnd_cor.

Completely grass dominated areas (class IV) are more abundant in the vegetation structure map than in the three other data sources, while areas with little grass cover (class I) are more frequently mapped in both field-driven maps (Figure 5). Only for category III (51-90%) all sources are in agreement. Correlation analysis shows that the vegetation structure map has a stronger correlation with the ground samples (0.90) than the SMA analysis for segmented objects (0.75). At the same time the correspondence is much better for the SMA analysis per segmented object (0.75) than per vegetation map object (0.62). Therefore the SMA per vegetation map object (unmixveg) was omitted from further analyses. The confusion matrix between the field samples and the vegetation structure map shows that grass encroachment is overestimated in extreme situations for the structure map, e.g. for < 10% grass and more than 70% (Table 2).

	Vegetation map (structure) 2009					
Groundthruth	1: <10% (Grass	2: 10-50% Grass	3: 51-90% Des flex	5: 91-100% Des flex	6: 91-100% Mol Cae	Total
1:0-10%	**55.7**	18.6	16.9	8.9		100.0
2:10-20	**74.0**	8.7	17.3			100.0
3:20-30%	**85.6**			14.4		100.0
4:30-40%	31.7	**68.3**		0.0		100.0
6:50-60%	5.4	19.6		51.8	23.2	100.0
7:60-70%	50.0			0.0	50.0	100.0
8:70-80%		33.3		**66.7**		100.0
9:80-90%		35.0		30.0	35.0	100.0
10:90-100%				34.1	**65.9**	100.0

Table 2. Confusion matrix between vegetation map for grass encroachment and the field samples.

However, it has to be noted here that the structure map makes an estimate for a complete patch while the field sample has only a radius of 3 m. In other words, large differences can occur within one patch as demonstrated by cat. 6 (50-60%) which falls for 50% in structural class 1 (<10%) and 50% in class 6 (91-100%). Table 3 shows more balanced figures, in which segments with a low amount of grass encroachment are in reality also classified by the low amounts of grass encroachment by the SMA, and vice versa. Nevertheless, for specific classes, e.g. 8 and 9 (70-90%) the SMA shows a clear underestimation.

	SegHgmdclip (Segmentation and unmixing)										
Groundtruth	0-10%	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	> 90	Total
1:0-10%	**37.3**	14.1	11.6	8.2	10.8	6.6	3.9	0.0	1.8	5.7	100.0
2:10-20	**52.7**	12.0	9.3	16.7	9.3	0.0	0.0	0.0	0.0	0.0	100.0
3:20-30%	15.5	**45.4**	13.4	25.8	0.0	0.0	0.0	0.0	0.0	0.0	100.0
4:30-40%	0.0	31.7	**68.3**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
6:50-60%	17.9	7.1	23.2	0.0	3.6	0.0	**48.2**	0.0	0.0	0.0	100.0
7:60-70%	0.0	0.0	0.0	0.0	0.0	**19.2**	**30.8**	**50.0**	0.0	0.0	100.0
8:70-80%	31.0	0.0	2.4	**66.7**	0.0	0.0	0.0	0.0	0.0	0.0	100.0
9:80-90%	0.0	0.0	30.0	**70.0**	0.0	0.0	0.0	0.0	0.0	0.0	100.0
10:90-100%	0.0	0.0	0.0	0.0	0.0	**34.1**	0.0	**34.1**	**31.7**	0.0	100.0

Table 3. Confusion matrix between SMA zonal statistics for the segmental objects and the field samples.

	Seg & unmix									
Vegmap	0-10%	20-30	20-30	30-40	40-50	50-60	60-70	70-80	80-90	>90
1: <10%	**73.9**	**65.9**	**60.7**	**40.9**	**36.2**	27.2	14.1	11.4	20.7	28.8
2: 10-50%	13.9	12.2	20.4	24.6	10.4	16.6	4.9	6.5	6.7	0.7
3: 51-90%	5.7	11.7	7.6	12.9	25.5	15.9	26.2	10.6	20.4	2.6
4: 91-100%	6.5	10.2	11.2	21.6	27.9	**40.2**	**54.8**	**71.5**	**52.2**	**67.9**
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4. Confusion matrix between SMA zonal statistics for the segmental objects and the structural classes of the vegetation map.

Table 4 is interesting and shows that the structural classes of the vegetation structure map tends to extremes. It has a strong preference for low categories (< 10 %) and high categories (> 90%). The underestimation of cat II) 10-50 % is also confirmed by Figure 5. Although it is difficult to make directly straightforward conclusions, these results have consequences for monitoring of grass encroachment.

4. CONCLUSIONS

The objective of the study was to compare the results from spectral mixture analysis in combination with segmentation of hyperspectral AHS imagery to traditional vegetation mapping methods. Conclusions should be made with care and additional research is required. However, it is clear that grass encroachment can vary to a large extent within one patch of the vegetation map, and that segmentation within these objects in combination with the spectral mixture analysis can reveal this. It seems that spectral mixture analysis alone or in combination with the segmented vegetation patches can provide very useful information for terrain managers, although the accuracy needs improvement. An important advantage is that a broader range of categories (1:0-10%, .., 10: 90-100%) provides much better opportunities for monitoring than the original categories (I:IV) of the vegetation structure map, especially since the latter categories seem to be biased towards very high or low percentages of grass encroachment. Aggregation of the continuous fraction maps from the SMA analysis to vegetation patches provided by segmentation techniques will probably improve classification accuracies, but this requires more research. Discussions with ecological field surveyors indicated that the usually complicated patches obtained through segmentation techniques from satellite imagery or digital aerial photography are often not well appreciated (especially at habitat level). This indicates that it is probably wise to segment only at the sublevel of management units. Discussions also revealed that change detection by traditional methods is difficult if different surveyors monitor the same terrain in time, and that combination with expertise from remote sensing experts can be useful.

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6. REFERENCES

Biesemans, J., Sterckx, S., Knaeps, E., Vreys, K., Adriaensen, S., Hooyberghs, J., and Deronde, B., 2007. Image processing workflows for airborne remote sensing. Proc. 5th EARSeL Imaging Spectroscopy Workshop, April 2007, Bruges, Belgium.

Blaschke, T., 2010. Object based image analysis for remote sensing. *ISPRS Journal of Photogrammetry and Remote Sensing*, 65, 2-16.

Burnett, C. & Blaschke, T., 2003. A multi-scale segmentation/object relationship modelling methodology for landscape analysis. *Ecological Modelling*, 168, 233-249.

Council of Europe, UNEP, ECNC, 1996. The Pan-European Biological and Landscape Diversity Strategy: a vision for Europe's natural heritage. Strasbourg, Council of Europe Publishing.

EU Council Directive, 1992. Natura 2000 Network on the conservation of natural habitats and of wild fauna. Council Directive 92/43/EEC (1) of 21 May 1992. The Council of the European Communities.

European Commission, 2005. Note to the Habitats Committee. Assessment, monitoring and reporting of conservation status – Preparing the 2001-2007 report under Article 17 of the Habitats Directive. DocHab-04-03/03 rev.3. Brussels: EC.

ETC/BD, 2006. Assessment, monitoring and reporting under Article 17 of the Habitats Directive: Explanatory Notes & Guidelines. Final draft, October 2006. Paris: European Topic Centre on Biological Diversity.

ETC/BD, 2008. Habitats Directive Article 17 report (2001-2006). Chapter 2: Data completeness, quality and coherence. Paris: European Topic Centre on Biological Diversity.

Duro, D.C., Coops, N.C., Wulder, M.A., Han, T., 2007. Development of a large area biodiversity monitoring system driven by remote sensing. *Progress in Physical Geography*, 31 (3), pp. 235-260.

Gillespie, T.W., Foody, G.M., Rocchini, D., Giorgi, A.P., Saatchi, S., 2008. Measuring and modeling biodiversity from space. *Progress in Physical Geography*, 32 (2), pp. 203-221.

Rosso, P.H., Ustin, S.L., and Hastings, A., 2005. Mapping marshland vegetation of San Francisco Bay, California, using hyperspectral data. *International Journal of Remote Sensing*, 26, pp. 5169-5191.

Smith, M. O., Johnson, P. E., and Adams, J. B., 1985, Quantitative determination of mineral types and abundances from reflectance spectra using principal component analysis. *Journal of Geophysical Research,* 90, C797-C804.

Schmidtlein, S., Zimmerman, P., Schüpferling, R., Weiβ, C., 2007. Mapping the floristic continuum: ordination space position estimation from imaging spectroscopy. *Journal of Vegetation Science*, 18, pp. 131-140.